Nuclear Science Division Newsletter

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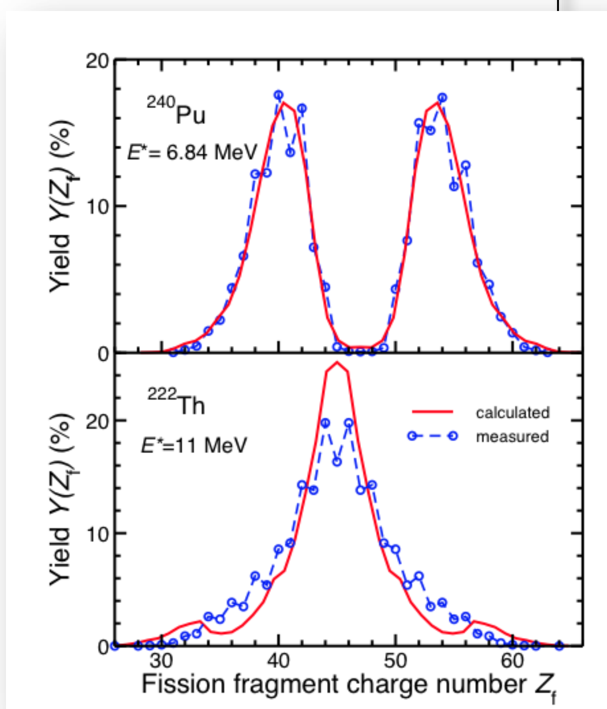
A random walk through fission

In nuclear fision a heavy nucleus transforms itself into two lighter nuclei, the fission fragments, whose individual mass numbers vary from one fission event to the next. This spectacular process is of great practical interest, for example for power generation, and it provides a rich testing ground for nuclear physics models. Since its discovery in 1939, the fission process has long been qualitatively understood as an evolution of the nuclear shape, but no quantitative model with demonstrated predictive power has yet been developed.



The distribution of the fission fragments in terms of their charge number 7.

This situation changed dramatically with the recent advent of a very simple (and essentially parameter free) treatment that yields unprecedented agreement with measured fission fragment mass yields, as illustrated in the figure for fission of ^{222}Th (for which the fragment masses are relatively similar) and ^{240}Pu (which favors asymmetric splits). This novel method was conceived by NSD's Jørgen Randrup and the applications were made in collaboration with Peter Möller (LANL) who has previously calculated the required deformation energies for a large number (thousands) of fissionable nuclei.

In the new approach (J. Randrup & P. Moller, Phys. Rev. Lett. 106, 1132503 (2011)), the evolution of the nuclear shape is akin to Brownian motion: the potential energy of deformation provides a driving force that seeks to lower the deformation energy, while the nucleon gas inside the nucleus provides a thermal reservoir that produces a dissipative force on the surface. Its average acts as a damping of the surface motion, while the random remainder renders the shape evolution diffusive, as is observed for a heavy body immersed in a fluid.

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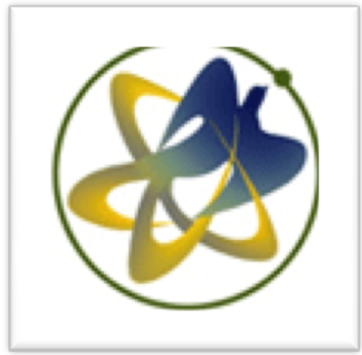
Berkeley consorts for Nuclear Science and Security

A UC Berkeley-led consortium of seven universities, with four national laboratories, including LBNL, with was recently awarded a $25M, five-year grant from the Department of Energy NNSA Office of Proliferation Detection. The consortium will largely focus on education and hands-on training of undergraduate and graduate students in core set of experimental disciplines that support the nation's non-proliferation and nuclear security mission: nuclear physics, nuclear chemistry, nuclear instrumentation, and nuclear engineering. The Nuclear Science and Security Consortium (NSSC) educational institutions include Michigan State University (MSU), the University of Nevada, Las Vegas, and Washington University in St. Louis, as well as well four University of California campuses (Berkeley, Davis, Irvine, and San Diego) and the University of California Institute on Global Conflict and Cooperation.

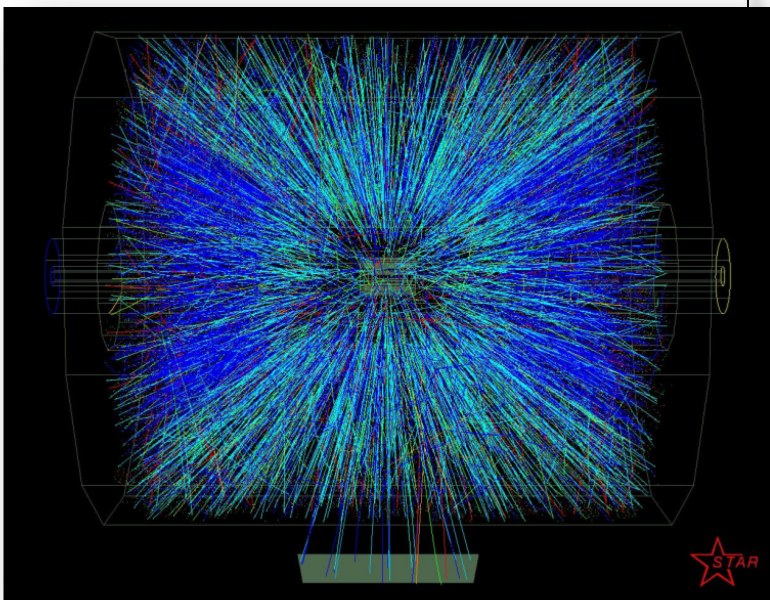


LBNL is playing a key role in the consortium, with Physics Division Director Jim Siegrist serving as executive director of the NSSC, helping principal investigator & UC Berkeley professor Jasmina Vujic. The Nuclear Science Division (NSD) will play an important role in this consortium as two NSD scientists lead two focus areas, Heino Nitsche in nuclear chemistry and Kai Vetter in nuclear instrumentation. The newly established Applied Nuclear Physics group provides a pivotal interface as its research is closely related to the research and associated laboratories and instrumentation to be established at UC Berkeley's Nuclear Engineering Department. In addition, facilities such as the low-background counting facility or the semiconductor detector laboratories will benefit from this new award, as it will provide opportunities for upgrades as well as student and junior researcher involvement. Other possibilities exist to enhance programs in low-energy nuclear physics such as nuclear structure research or research associated with low backgrounds and low noise, for example the search for the neutrino-less double beta decay or the coherent nuclear-neutrino scattering process. Here, the involvement of MSU provides excellent opportunities with its already existing and future radioactive beam facilities. The consortium will also draw on other groups in NSD and other LBNL divisions. LBNL's Accelerator and Fusion Research and Life Sciences Divisions are expected to be involved, for example in detector materials research or active interrogation techniques.

Connecting heavy-ion collisions with lattice QCD

Quantum chromodynamics, the theory describing the strong interaction poses some unique experimental problems. Because the interaction strength increases at low energies, perturbation theory can only be used in special cases involving very energetic interactions. Although numerical lattice gauge calculations have had recent success in predicting hadron masses, it had not previously been used to study dynamical interactions at low energies.

A recent paper in Science [S. Gupta, X.F. Luo, B. Mohanty, H.G. Ritter, and N. Xu, Science 332, 1525 (2011)] reports on the first test of QCD theory in the nonperturbative, long-distance regime of high temperature bulk matter. Lattice QCD calculations of various orders of susceptibilities using conserved net-baryon number were performed; the susceptibilities characterize the response of the system to the addition of a small amount of matter (e.g. one quark or one baryon). These results were compared to corresponding experimental observables. Here "net" refers to the difference in particle and antiparticle numbers. The experimental observable is based on the shape of the event-by-event net-proton number distribution, an experimentally measurable approximation for the net-baryon number distribution, in Au+Au central collisions at $\sqrt{s_{NN}}$ between 20 and 200 GeV from the STAR experiment at RHIC.



One of the STAR events used in the comparison.

The agreement between experimental measurements of higher order fluctuations and the lattice QCD results provides clear evidence of thermalization in nuclear collisions at RHIC. It also marks the first successful direct test of QCD in the non-perturbative context of high temperature hadronic matter. In addition, the authors extracted the transition temperature between hadronic matter and a quark-gluon plasma at zero chemical potential as T_C = 175 (+1)(-7) MeV. This translates to about 200 trillion Celsius, by far the largest temperature at which laboratory experiments have probed matter. For a comparison, the surface temperature of the sun is about 5600 Celsius. This study marks the beginning of a new era of quantitative studies of QCD matter.